ON THE FORMATION OF HEAT IN THE SALIVARY GLANDS.

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HISTORY.

Ludwig and Spiess(1) in 1857 and Ludwig(2) in 1860 determined the submaxillary saliva of the dog to be from 1° C. to 1·5° C. warmer than the blood in the carotid artery.

The thermo-electric junction method was employed by Ludwig and Spiess, the thermometric method by Ludwig. The present research was undertaken by us in order to investigate the formation of heat under the varying conditions of stimulation of either the chorda tympani or of the cervical sympathetic nerves. Bernard(3) had found that stimulation of the chorda tympani produced a rise of temperature, and that a slight rise still occurred after ligature of the vessels. On the other hand, the stimulation of the sympathetic produced a fall of temperature which he asserted was still recognisable after ligature of the vessels of the gland.

Bernard does not state to what degree the temperature changes reached, nor whether the temperature attained to was higher than that of the arterial blood.

Heidenhain(4) made one or two tentative experiments on the effect of sympathetic stimulation, and his observations as far as they went pointed to a rise of temperature.

METHODS OF RESEARCH.

Considering the large results obtained by Ludwig and Spiess under conditions of apparently most careful experimentation, there seemed to be little difficulty in the research we proposed, but we unexpectedly found it quite impossible to obtain any constant results by the methods of Ludwig and Spiess, and finally have been brought to the position of denying that any measurable formation of heat can be demonstrated in salivary glands.

I. *The wire-resistance thermometer.*

(1) In the dog. We first employed the wire-resistance method of investigating temperature changes which was so successfully used and is fully described by Rolleston(5) in a paper on the formation of heat in the nerves of the frog.

We threaded one wire through the gland which was to be stimulated to activity, and the other wire through the gland on the opposite side which remained at rest. This method had to be abandoned owing to the impossibility of maintaining any constancy in the resistances of the two wires threaded through the warm tissues of the dog; the slightest movements, such as those caused by artificial respiration in the curarised animal, were sufficient to produce deflections of the galvanometer even when the animal's head was enclosed in an air-bath kept at a constant temperatûre.

We therefore came to the conclusion that the resistance thermometer cannot be employed for the investigation of temperature changes in a warm-blooded animal.

(2) In the grass snake. We then attempted to employ the same method on a cold-blooded animal and chose for investigation the salivary gland of the common grass snake. The glands were threaded with the wires, rapidly excised and placed under a bell glass, and excited directly (see Rolleston(5)). From this experiment we could obtain no evidence of any measurable formation of heat.

II. *Thermo-electric junction method.*

(1) The method next examined was that of Ludwig and Spiess. Thermo-electric junctions were made of iron and German-silver wires soldered together. One junction was placed in the salivary cannula or in the substance of the gland, the other junction was placed either in the central end of the opposite carotid or in a glass T-cannula which was inserted into the carotid and through which the blood continued to circulate. The wounds, after placing the junctions in position, were

closed and protected with cotton-wool. This method gave us such inconstant results, that we came to the conclusion, after fifty to sixty experiments carried on during the last two or three years, that owing to clotting and interference with the circulation, the temperature of the carotid junction could not be looked upon as the real blood temperature.

We then placed the animal's head in a warm air-bath kept at the temperature of the rectum and repeated this method of experiment, but were again unable to obtain any positive results.

The final method of this research.

It will be remembered that Bernard proved that, in consequence of the velocity of the blood-flow, the temperature is the same in all the large arteries.

Having therefore reached the above conclusion we next carefully insulated one thermo-electric junction, and passed it up a gum-elastic catheter, so that the junction lay exposed in the eye of the catheter. The femoral artery in a large dog was then exposed and the catheter pushed up into the aorta, so that the junction was exposed to the full blood-stream. The pulsation of the opposite femoral showed that the circulation was unimpaired. The second junction was placed in a glass T-cannula which was in connection with (1) the salivary cannula and (2) a tube for filling the T-cannula with warm water. The glass T-cannula was two inches long and was made of thick small-bored manometer tubing. The silver salivary cannula was so short that the junction of this with the T-cannula lay within the wound. The junction was effected by half-an-inch of fine rubber tube. Before and after each experiment the junctions were proved to be completely insulated.

The galvanometer employed was a Thomson low-resistance, reflecting instrument.

A difference of 1° C. between the junctions was found to give a deflection of the spot of light of 30° of the scale employed.

When we had placed the junctions in position, the blood junction was of course found to be warmer than the salivary junction which lay in the empty and exposed T-cannula. Warm water was therefore run through the T-cannula until the salivary junction was warmed up to the same temperature as the blood and the spot of light was brought to zero. A clip was then placed on the feeding tube from the warm water reservoir. The glass T-tube, thus left full of warm water at the temperature of the blood, was next covered with wool, and the wound closed round the salivary cannula and protected with wool. The free end of the T-cannula was alone left exposed from which the flow of saliva could be observed. By this means the zero point was maintained long enough for the excitation of a free flow of saliva, or the fall of temperature in the T-cannula was only five to ten divisions of the scale during a time equal in length to the excitation period.

During such a period the gland being excited to activity, the secretion of saliva and the galvanometer deflection were noted.

Under these conditions the saliva never proved to be warmer than the aortic blood.

If the salivary junction were made slightly warmer than the blood the saliva cooled the junction slightly beyond zero; if the junction were made slightly cooler than the blood the saliva warmed it almost to zero.

These results appear in the following typical experiment.

Jan. 22, 1894. Very large smooth black dog.

Anæsthetics. Chloroform and morphia.

The dog was kept warm on a hot water tin.

Catheter junction in aorta, salivary junction in T-tube with warm water apparatus.

+ = blood warmer.

At the beginning of the experiment warm water was run into the T-cannula till the galvanometer stood at + 10.

Time.	Nerve.	Deflection.	Secretion.
1.10 p.m.	Chorda	+ 10 to + 5	Very free.

Warm water was then run in till the galvanometer stood at – 5.

1.20	Chorda	– 5 to + 2	Very free.
1.21	"	+ 5 to + 2	"
1.22	"	+ 5 to + 2	"
1.23	"	+ 9 to + 2	"

Warm water added till the galvanometer stood at + 2.

1.21	Chorda	+ 2 to + 2	Very free.
1.31	"	+ 10 to + 2	"

The stimulation was then maintained for three minutes, the spot of light remained steadily at + 2, the saliva still flowed at the end of the experiment.

On placing the salivary junction in the tissues of the wound round the salivary cannula after the above experiment the temperature was found to be the same as that of the aortic blood.

The result was the same if the salivary junction was placed in the substance of the submaxillary gland. If the wound was closed and covered with wool the galvanometer needle soon took up the zero or almost the zero point. Thus:—

Jan. 31, 1894. Large Fox-Terrier.
Anæsthetics. Chloroform and Morphia.
The dog was kept warm on a hot water tin.
Catheter junction in aorta, salivary junction in submaxillary gland.

Time.	Nerve.	Deflection.	Secretion.
1.40	Chorda	0 to 0	Free

The carotid artery was then clamped in order to eliminate the possible cooling due to the rapid flow of blood through the gland. Thus:—

Carotid clamped and immediate stimulation.

Time.	Nerve.	Deflection.	Secretion.
1.45	Chorda	0 to 0	moderate

Stimulation of the Sympathetic nerve gave us equally negative results.

Mercurial Thermometer Method.

We finally investigated Ludwig's method of experimentation with Geissler's thermometers.

We carefully compared the thermometers with one another in warm water before the experiment.

It will be remembered that Geissler's thermometers consist of a bulb, a naked stem, and the calibrated part of the stem enclosed in a glass jacket. In order to obtain readings which accurately agree of any two thermometers, it is necessary to cover a certain empirical amount of the naked stems with the warm water.

Under this condition our thermometers corresponded exactly in the range of temperature of the experiment in warm water. On the other hand it is very difficult to be sure that exactly the same amount of the stems are covered by tissues of the same temperature along the whole line of the stems, when the thermometers are placed in position in an animal; and this makes the thermometric method far inferior in exactness to the thermo-junction method.

One thermometer was introduced up the femoral artery of a large dog into the aorta, the other thermometer was placed in the glass T-cannula which was connected with the hot water reservoir and the salivary cannula as before. The corresponding amount of stem was enclosed in the T-cannula to that in the artery.

The thermometer in the empty T-cannula was of course colder than the aortic thermometer. Warm water was therefore run in till the temperature of the T-cannula was the same as, or slightly above, that of the aorta. The T-cannula was then covered with cotton-wool and the wound closed round the salivary cannula and covered with wool. Under these conditions the salivary thermometer when left to itself cooled ·5° C. in two minutes.

EXPERIMENT.

Feb. 5, 1894. Large Retriever Dog.

Anæsthetics. Chloroform and Morphia.

The dog was rapidly prepared and kept warm on a hot water tin.

Blood temperature = 38·6.

Salivary thermometer was warmed up to 38·7 before the experiment.

	Time.	Nerve.	Length of stimulation.	Blood Temp.	Salivary cannula Temp.	Secretion.
(1)	1.10 p.m.	Chorda	30″	38·6	From 38·7 to 38·2	Very free

Salivary cannula warmed up to 38·9.

	Time.	Nerve.	Length of stimulation.	Blood Temp.	Salivary cannula Temp.	Secretion.
(2)	1.15 p.m.	Chorda	60″	38·6	From 38·9 to 38·1	„

The thermometer was then taken out of the salivary cannula and pushed down the central end of the carotid artery, till the stem was covered for four inches, the amount corresponding to the stem of the aortic thermometer.

The wound was then closed and protected as in the method of Ludwig.

The temperature was then found to be

	Aorta.	Carotid central end.
	38·3	37·7
One hour later	37·6	37·2

EXPERIMENT.

March 5, 1894. Large Retriever dog.

Anæsthetics. Chloroform and Morphia.

The dog was very rapidly prepared and kept warm on a hot water tin. During the whole experiment the blood temperature remained steadily at 38·6.

(1) Temperature in the aorta 38·6.

(2) The thermometer was passed into the arch of the aorta.

Temperature in the arch of the aorta 38·6.

(3) The thermometer was placed four inches down the central end of the carotid and the wound closed.

Temperature in the central end of the carotid 37·9.

(4) The thermometer was pushed down into the tissues round the gland.

Temperature by the submaxillary gland 37·9.

(5) The thermometer was pushed down into the deep tissues of the neck on the gland side till it lay on a level with the thermometer in the central end of the carotid.

Temperature of the deep tissues of the neck 38·6.

(6) The salivary thermometer was placed in the T-cannula and the blood thermometer in the aorta. Blood = 38·6. The salivary thermometer was warmed up with warm water to a temperature of 39°. The wound and cannula were covered with wool and the thermometer was then found to cool ·5° in three-quarters of a minute.

(7) The salivary thermometer was warmed up to 40°, and then, twenty minutes after the animal was anæsthetised, 10 m. of a 2 p.c. solution of pilocarpin was injected into the pleural cavity. Saliva began almost at once to pour out of the cannula in most copious quantities and the thermometer ran down at once to 37·9° and finally maintained a steady position at 37·7°. The saliva balancing the loss of heat from the T-cannula (·5° in $\frac{3}{4}$ minute) at that temperature.

From the first of these experiments it can be seen that the saliva might prove warmer than the temperature indicated by the thermometer in the central end of the carotid. Both experiments show that the temperature of the central end of the carotid cannot be taken as the true blood temperature.

The second experiment shows that the saliva is no warmer than the gland and tissues round the duct. In this experiment the room was cold, 16° C., and the superficial tissues were colder than the aortic blood.

On the fact that the central end of the carotid does not give the true blood temperature depends we believe the discrepancy between Ludwig's observations and the observations we have here recorded. There is no circulation of blood round the thermometer, in this position the blood simply pulsates against the bottom of the bulb, while the stem lies in tissues deprived of circulating blood.

The same explanation will account for the results of Ludwig and Spiess' experiments with thermo-electric junctions. These authors placed their blood junction in a brass cannula(6) of special construction used for determining lateral arterial pressure. This was inserted into the carotid and the blood circulated through this and round the junction.

The wound was then closed and protected and the junctions left for 15 minutes to take up a constant temperature. From our own very numerous experiments on this method we believe that clotting must have taken place during this period, and that therefore the true blood temperature was never attained and then, owing to the continued free circulation on the side of the gland, the saliva would prove to be warmer than the carotid junction. For we have determined that the temperature in the arch of the aorta is the same as in the abdominal aorta, and that the temperature of the gland and tissues in a warm room and protected animal is often almost as high as that of the aortic blood.

Finally, in support of our negative results, we can quote Chauveau and Kaufmann's (7) experiments on the blood gases of the parotid in a resting and in a chewing horse, and on the amount of glucose which disappeared in the gland under these varying conditions.

Only one gas analysis proved successful, owing to the horse always munching on the wrong side of its mouth. This yielded the following differences between 100 grms. of venous and 100 grms. of arterial blood.

	Rest.	Activity.
O absorbed	3·9 c.c.	2·7
CO_2 produced	2·1	·2
Total	6	2·9 × 3 = 8·7.

The amount in activity was multiplied by three, because the rate of blood-flow was found by these authors to be three times faster during activity than during rest.

This single experiment is so inconclusive that no stress can be laid upon it. In their experiments on glucose Chauveau and Kaufmann found that in 1000 grms. of blood ·002 grm. more glucose disappeared in the gland during activity than during rest.

Taking the heat produced by the complete combustion of 1 grm. of glucose as 3277 (Frankland), the combustion of ·002 grm. glucose would heat the 1000 grm. blood about ·0016° C. But it must be remembered that gland, tissues and saliva would also share in this heat.

Granting that other bodies were broken down as well as glucose and that the heat produced was ten times greater, yet it is obvious that this amount of heat spread over blood, gland, saliva and tissues and formed during the circulation time of 1000 grm. of blood, would be quite an immeasurable quantity. On the other hand, Chauveau and Kaufmann found that the expenditure of glucose was three and a half times as great during activity than during rest in muscle.

CONCLUSION.

Considering the nature of the salivary secretion, the smallness of the salivary gland, and the amount of blood racing through the gland during activity, and the fact that arterialised blood issues from the gland veins during activity, it is highly improbable that any measurable amount of heat is formed in the gland. And from our experiments we conclude that no formation of heat can be directly determined in the submaxillary gland by any known method of measuring variations in temperatures.

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